FABRICATION AND ERECTION OF PFCM BRIDGE IN INCHEON BRIDGE PROJECT: CONSTRUCTION SUPERVISION OF INDEPENDENT CHECKING ENGINEER

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Abstract: *This paper presents several major tasks which are critically managed by the supervision team in the supervision process for the construction of the approach bridge in the Incheon Bridge applied the precast free cantilever method (PFCM). The Incheon Bridge Supervision Team established and managed various independent construction engineering processes to achieve self-reliant technological judgement and prompt decision-making in order to prepare for any kind of unforeseen event that might happen during the construction of the bridge. We believe that this kind of construction engineering activities contributes in the successful completion of the project as being mutual assistant to the constructor.*

Keywords: Precast segmental bridge, Balanced cantilever method, Analysis of construction stage

1. INTRODUCTION

The approach bridge of Incheon Bridge erected by the precast free cantilever method (PFCM) are a 7-continuous span PSC box girder type bridge linking the cable-stayed bridge and viaducts. This bridge with main span of 145m exhibits 3-dimensional tapered shape and it is the first and largest sea-crossing precast segmental bridge that has ever been erected in Korea. In particular, a typical feature of the bridge is that the superstructure is mostly fabricated in precast members, and especially a total weight of 1,400ton and a total length of 20m precast segments are erected on the pier by using a large-sized floating crane. Therefore, the lack of knowledge due to the lack of experience in the construction of a bridge of such scale was a tremendous burden at the beginning of the construction. And, there were many of concerns about our chance to achieve safety and high quality as well as to attain the target construction progress successfully.

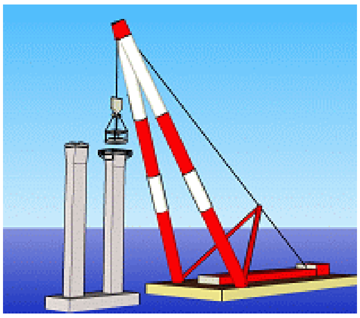
This paper intends to present the major construction items during the construction process of the bridge that have been managed during the various technological checks conducted thru the independent construction engineering activities established by our supervision team.

Figure 1: View of the PFCM erection

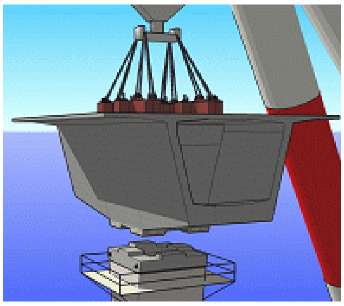
2. PREVIEW

2.1 SUMMARY OF CONSTRUCTION

The approach bridges of Incheon Bridge were erected by the balanced cantilever method (BCM), which were carried out by lifting 3~4m length of small precast blocks and placing them on both side of the pier while maintaining the balance of the pier's both side. Prior to the erection, the match cast blocks (MCB) and large blocks fabricated in advance at the onshore workshop are transported offshore to the site. And they are erected to complete the construction of the pier table. The derrick crane is then installed and the small blocks are lifted from the barge. The cantilever is completed by erecting successively the small blocks by epoxy application and pre-tensionning introduction. Once the erection of the segments at the contiguous piers is done, the precast key segment is then lifted and the central span is closed. When the erection of key segments of all the spans is completed, the end segments of the end span are erected. The construction of the girder is finally finished by achieving the continuity of the whole span through tensioning of the external tendons.



(a) MCB erection



(b) Erection of large block

Figure 2: Construction method of pier table Figure

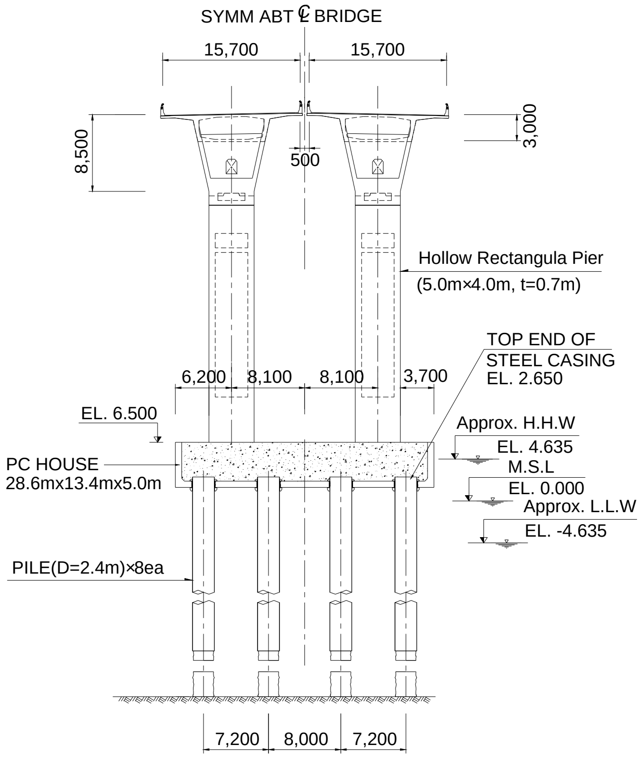


Figure 3: Cross-sectional view of approach bridge

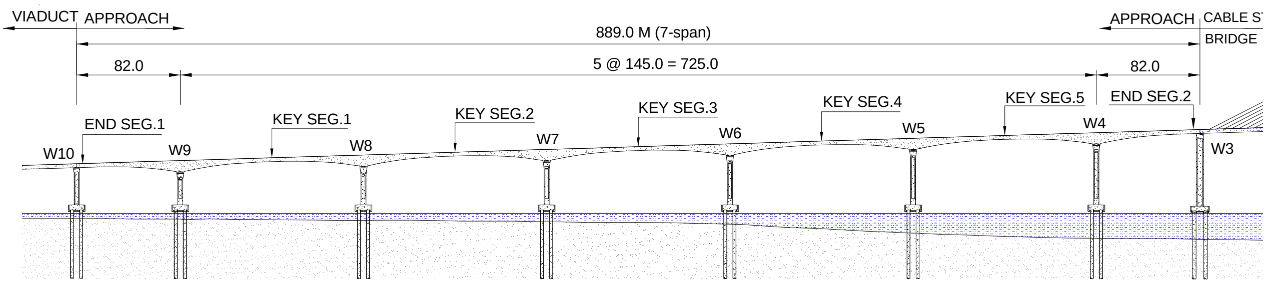


Figure 4: Longitudinal view of approach bridge (west side)

2.2 CHECKING PROCESS FOR CONSTRUCTION MANAGEMENT

The precast segmental bridge experiences continuous change of the deflection according to the change of the structural system and change of the load at each construction stage. Accordingly, design that considers rationally the erection characteristics on site shall be conducted, and implementing the erection throughout a construction sequence in agreement with the design is advisable. However, it is likely that several modifications of the erection sequence would be unavoidable in order to contribute to rational shortening of the construction period and prevent interference with the works in other sections through the improvement of the construction method, and prepare for the occurrence of conflicting construction conditions that were not expected in the design stage. In such case for Incheon Bridge project, the revision of the design should be implemented with respect to the specified design approval procedure, but our supervision team also fulfilled its tasks by establishing separately the independent checking process shown in figure 5. The concept underlying this independent check differs from the duties of the design supervisor (DS) of the concessionaire or the contractor’s checking engineer (CCE) of the contractor. It is a check process established by the supervision team to achieve smooth and regular erection management of the approach bridges applying the PFCM.
By performing this check, the analysis model is reconstructed independently based on the construction planning and construction detail drawings without knowledge of the input data applied in the design. Such process guarantees the rights of the design and constructor as well as secures complete objectivity of the structural analysis results. In addition, some technical advisory opinions are also referred if some 3rd party verification is necessary.

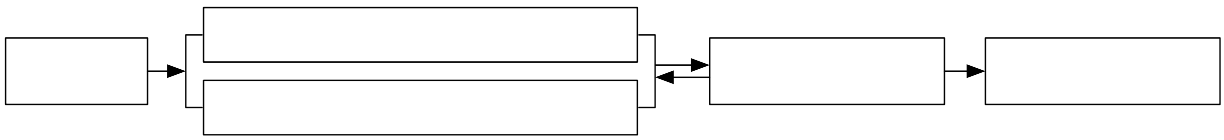


Figure 5: Independent supervision checking process for PFCM construction management

2.3 CHECKING OF CONSTRUCTION STAGE ANALYSIS

■ Analysis model

Prior to the execution of the construction, independent construction stage analysis was performed to check the appropriateness of the fabrication camber and deflection management data per construction stage provided in the design. This check was carried out to execute thorough management of the camber (deflection) as a critical item of the applicability of the construction method. The general-purpose structural analysis program Midas Civil 2006 developed by MIDAS IT in Korea was used as analysis program. The meaningful loadings considered during the construction stage analysis are as follows:

- Self-weight of concrete per stage
  - Self weight: computed by program
  - Bulk head, butress, PT block: additional load
- Segment lifting load per stage
- Weight of derrick crane and repositioning of crane by stage
- Introduction of prestress per stage
- Time-dependent material (CEB-FIP model code, 1990)
  - Creep/shrinkage, compressive strength
- Change of the structural system according to key segment closure
- Introduction of horizontal pre-compensation force per stage
- Secondary dead loads like protection wall and pavement

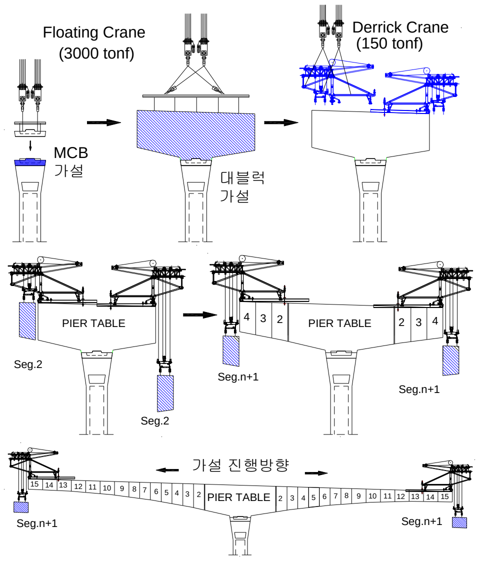


Figure 6: Erection sequence of single cantilever

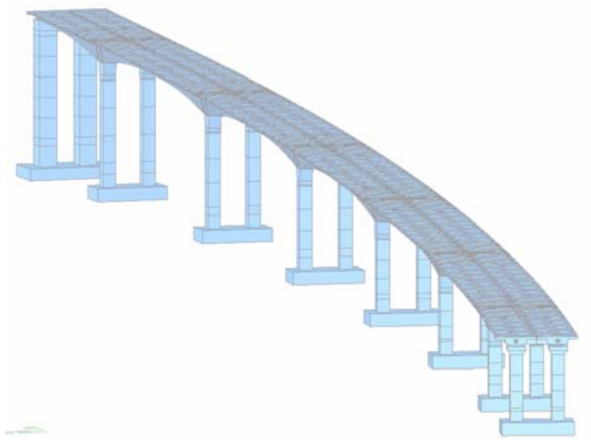
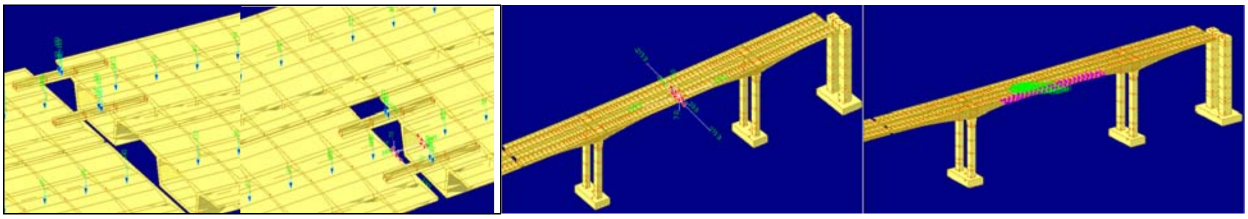


Figure 7: Three-dimensional analysis model

■ Composition of stage

The analysis model has been precisely reconstructed based on the design documents and construction planning so as to fit with the actual construction conditions. Considering that the eastern and western sides have different conditions, modelling was executed by reflecting the horizontal curve and longitudinal alignment. The physical values of the soil (6×6 spring coefficient) obtained from the results of the nonlinear analysis considering the soil-structure interaction were applied identically to the input adopted in the design. The weight of each segment was recomputed precisely and calibrated according to the relevant conditions. The detailed construction process of each segment was subdivided by stage including the lifting of small blocks, expoxy joint, tensioning of temporary steel bars, tensioning of tendons and progress of the derrick crane. All the tendons disposed in the longitudinal direction were defined identically to the profile reflected in the construction details and their disposition in 3-dimensional (x, y, z) curvature was precisely simulated. The spare tendons were also additionally considered so as to be easily activated if necessary. Moreover, the contruction time required for each stage was considered and the difference of the time-dependent load occurring from the erection of the single cantilever to the stand-by period until the erection of the key segment was modeled by applying the time load supported by the program. The installed position of the counterweight used during the erection of the key segment was considered as well as the load redistribution effect to both cantilevers provided by the leveling beam.



a) Load redistribution effect of leveling beam (b) Pre-compensation (c) Bottom tendon prestressing

Figure 8: Key segment analysis stage

In addition, the erection of the end segment and the construction stage of the external tendon were considered. The erection of the protection wall and laying of pavement were also included. The deflection occurring 30 years after the completion was selected as reference for the management of the fabrication camber and geometric configuration. The final stress during the operational stage was additionally checked considering the time effect until 70 years after the construction.

■ **Analysis results (after 30years of displacement)**

Analysis was performed using the so-constituted construction stage analysis model and the results were continuously compared and fed back with the results of the detail design. The conflicting items derived during this process were adjusted rationally through discussion and the items to be supplemented were reflected in the final design of the eastern approach bridge of which design was implemented at the time. Figure 9 plots the cambers after 30 years of operation resulting from the analyses of the designer and supervision team. The overall similarity of the camber curves can be observed.

And also, the deflection in the cantilever erection stage of all pier sections was compared with the deflection management details in stages. Our supervision team was able to conduct promptly structural safety check in case of occurrence of any kind of special event during the construction by using the established basic analysis model, and we checked all possible worst conditions in advance and prepared various action plans for each possible condition or event. The construction stage analysis was performed hundreds of times before the completion of the whole bridge construction works.

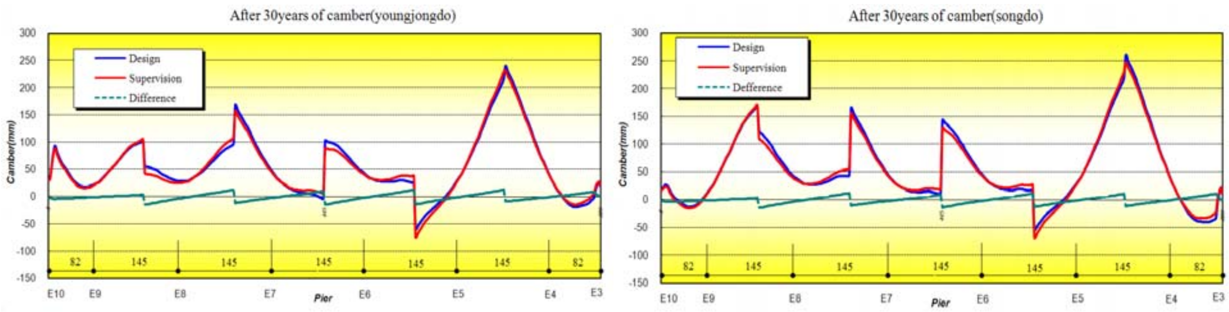


Figure 9: Comparison of analysis results (design vs. supervision)

3. CRITICAL MANAGEMENT ISSUE

3.1 Fabrication of segments

The constructed geometry of the precast segmental bridge being mostly determined in the workshop, precise geometry control should be implemented since the fabrication stage. The fabrication by short line cell method selected for the bridge requires extremely advanced technology for the geometry control. This implies also that the efficient management of the mould system becomes critical since having enormous influence on the fabrication and erection cycle time and being decisive to the success of the construction.

• ***Fabrication conditions***

The girder of the bridge is a twin box 1-cell type girder separating the 15.7m wide up and down lines. The longitudinal slope is 3% and the plane is curved (western side R = 3,250m, eastern side R = 3,740m) together with a varying cant section just before the connection with the cable-stayed bridge. As illustrated in figure 10, the height of the girder varies from 8.5m to 3.0m and the width of the lower slab also varies from 5.0m to 7.422m, which show that the superstructure exhibits very complex 3-dimensionally varying geometry. Such geometry promotes the elegance of the aesthetic appearance of the bridge but makes this bridge extremely fastidious in terms of fabrication and erection process.

Prior to the fabrication of the segments, in case of the west approach bridge where the construction work commences first, the results of the construction stage analysis were continuously revised with respect to the numerous executions of constructability check even after the approval of the design documents. Through this process, the final target value was decided. Accordingly, the supervision team executed once again the detailed check of the target fabrication values submitted by the constructor. Figure 11 illustrates the floating curve by inverse calculation of the 30 year-deflection after the construction. The position presented in the figure has a symmetric appearance. The camber curve on the analysis is the forth position showing severe ill-balance.

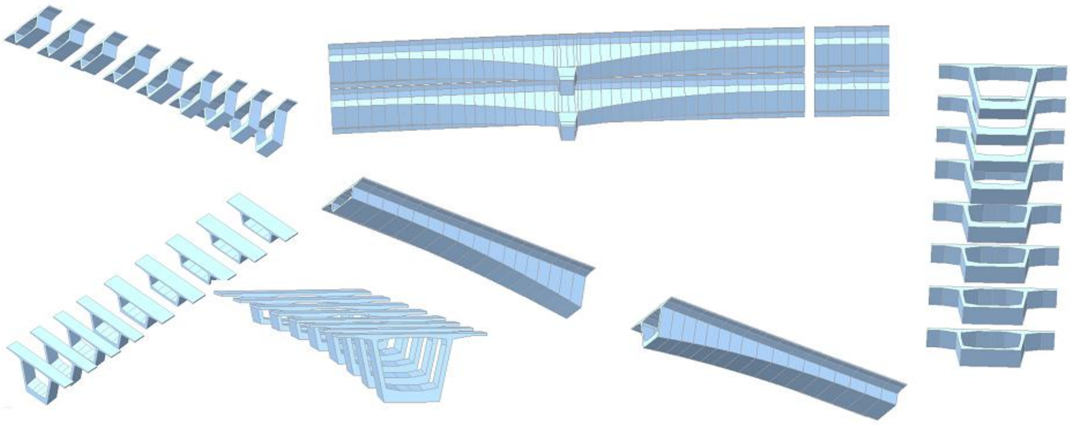


Figure 10: Simulation of superstructure girder

Besides, the direction of the fabrication of the segments of each pier in the mould system proceeds in both sides of Segment No. 2, which is the first small block located at the extremity of the large block as shown in figure 12. The segments were manufactured in 6 moulds divided according to the length and direction of the segments. The fabrication was implemented with respect to these manufacturing features.

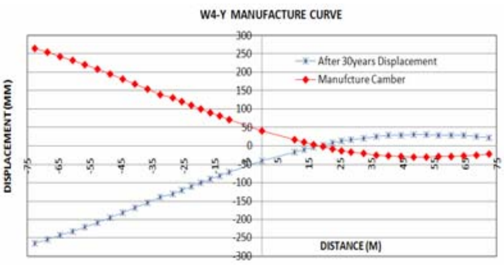


Figure 11: Manufacturing curve

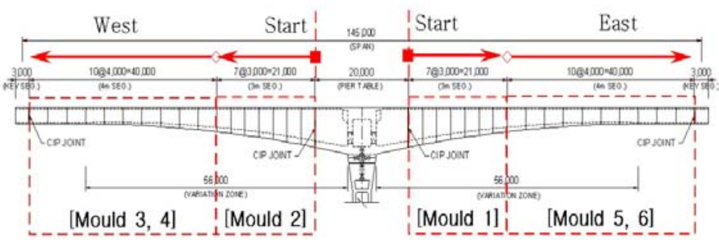


Figure 12: Manufacturing direction

• ***Fabrication geometry control***

The geometric shape of the segments fabricated by the short line method is determined through the form cell and match casting of old segment. In order to reflect efficiently the geometry data necessary for the fabrication, a geometry control program purposed exclusively for the fabrication is required. To that goal, the GCPS (Geometry Control for Precast Segment) program developed by the construction team of Samsung E&C has been adopted. Before the exploitation of this program, comparison was done with other programs (GEOCON, MC3D). The evaluation results of the independent check performed by a third party attested the high precision of the program and verified its reliability.

However, whatever precise performance is provided by the fabrication geometry control program, the program becomes obsolete without adequate connection with the operation of the mould system and measurement management system. Accordingly, the cooperative and harmonious management of these three systems is of extreme importance. Therefore, a separate team for the operation and management of the mould system was formed so as to derive items to be improved whenever feeling problems during the operation of the moulds. These items were improved by the construction manager and resulted in significant reduction of the trials and errors experienced at the beginning of the project. The productivity at the casting yard reached a speed that saturated the open-air yard after the stabilization of the mould operation system. In addition, the setting of the moulds was managed through a measurement process performed at each stage. In order to realize precise measurement at each match casting stage, a permanent dual team composed of the measurement team of the collaborating company and the measurement check team of the constructor was operated and final reverification was done through the check process of the supervisor.

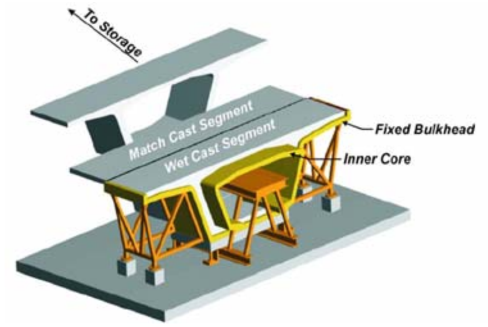


Figure 13: Short line method

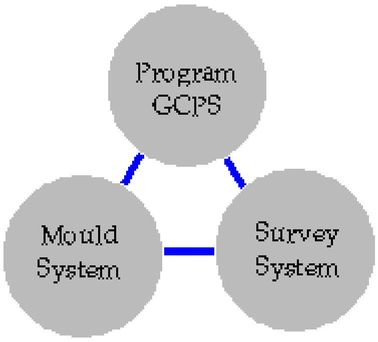


Figure 14: Geometry control system

Since the fabrication achievements are reflected in the fabrication of the next segment, the management of the as built measurement data obtained after curing of concrete is of critical importance. The inspection documents recording the fabrication achievements included the measurement log together with the level, distance, twisting and offset results. In addition, the fabrication geometry controller converted them into global coordinates using the GPCS program and submitted the "fabrication camber & twisting management drawing" and the "horizontal geometry management drawing" to the supervision team. These fabrication achievements were then rechecked through the coordinate inspection of the supervision team. Even if the supervisor received support of the GCPS program, check was conducted by generating results obtained using separate input of the data from the measurement log and comparison of these results with the submitted fabrication achievements. This process enabled to evaluate the setting target values to be reflected to the next fabrication. Such information was reused in the inspection duties of the supervisor for the fabrication mould.

This series of thorough cross checking prevented the occurrence of simple errors and mistakes (error in the sign convention, mistyping of input, etc.). This inspection process was never omitted neither by the contractor nor the supervisor and was conducted until the completion of the fabrication. This allowed successful and errorless fabrication of the 836 small block segments, which presented complex geometry.

• *Fabrication Procedure at Fabrication Yard*

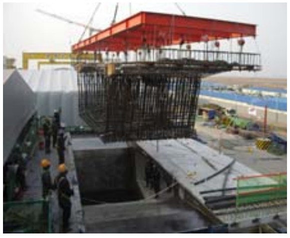
MCB and large blocks were cured by protective heat insulation curing method at 20°C for 3 days. Small blocks were cured by steam curing method at 60°C for 17~19 hours. When more than 31.5MPa of the compressive strength is secured, the transverse strands (5-12.5mm) were tensioned. The fabrication cycle time is 28 days required for large blocks and 2.5~3days required for small blocks.

MCB mould

Fabricated MCB

Large block mould

Fabricated large block



Installation of rebar cage

Placing of concrete

Steam curing

Separation of segments

Figure 15: Fabrication of segments in casting yard

3.2 Erection of segments

• ***Erection gometry control process***

As mentioned above, the geometry of the precast segmental bridge is almost completed through the fabrication achievements produced in the casting yard. However, the erection geometry exhibits difference with the fabricated camber during the construction due to diverse reasons. Even if compensation is performed on site, such solution is not recommendable and aggravates additional cost and construction delay. The most efficient solution is to perform calibration during the fabrication stage but reflecting the erection error in the fabrication stage in due time is quasi-impossible since fabrication is always conducted prior to the erection and several stages in advance to the actual construction stage.

Differently from the cast-in-place FCM bridge, the PFCM bridge erects segments that have been manufactured in advance. This means that the compensation of PFCM bridge will lead to stronger difficulty and more constraints in the case where the allowable construction error is exceeded during erection.

The construction geometry control error of the bridge, as the tolerance limits of the structure provided by the designer, is set to below ±75mm for the deflection and ±50mm for the geometry. To satisfy this error, a separate construction geometry control process has been established. This process, composed of a deviation management chart and deflection control diagram (Christmas tree) per construction stage, involved the programming to assess efficiently the expected progress of the erection considering the fabrication error and measurement at each erection stage.

A point to be carefully addressed during the construction geometry control is the guarantee of reliable measurement data. Since the bridge is composed of highly elevated piers located in a marine environment, the measurement fluctuated by about ±50mm in case of wind or severe waves, or when the cantilever extended to a certain length. In order to overcome this problem, a skilled measurement engineer was dispatched permanently on site to achieve consistent measurement and measurements were repeated at each erection stage. In addition, careful attention has been let to avoid measurement in occurrence of seesaw due to the heavy weights of the working equipment at the top.

• ***Compensation of construction error and analysis of construction process***

When the whole superstructure is erected by precast members like Incheon Bridge, the position of the pier table should be precisely constructed. Since this position is the reference point for the geometry control of all the segments, construction error at this place will have the largest effect on the erection alignment of the subsequent segments. However, it is obviously impossible to achieve errorless and precise construction when using a floating crane to lift a 1,400ton large block over a pier rising at 30m from the seawater level.

Accordingly, an intermediate member that is the MCB was disposed between the large block and pier coping forming the pier table so as to absorb firstly the construction error of the lower pier as shown in figure 16 for the approach bridges of Incheon Bridge. Then, the construction error of the pier table was absorbed by disposing CIP joint at a gap of about 15cm let at segment No. 2 connecting the large block and first small block. By such method, the erection of segment No. 2 could be executed through precise and thorough adjustment together with the setting of the MCB member.

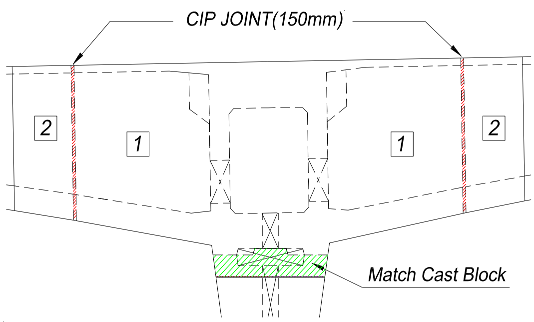


Figure 16: CIP joint of the pier table and segment No.2

① Reflection of the adjustment in the fabrication by applying the alignment compensation in advance in case where the fabrication of the segments is still under course for the relevant cantilever;
② Compensation by changing the angle of the dislocated alignment through the adjustment of the spacing of the shim plates inserted in the joints of the segments;
③ Compensation using the spare tendons provided in the upper slab when the both sides of the cantilever show sign of downward deflection;
④ When adjustment cannot be achieved by these methods, compensation by cast-in-place joint (wet joint) in the small gap let at the joints.

These compensation methods were actually applied during the erection of the approach bridges of Incheon Bridge.
Figures 17 and 18 present the erection geometry control sheets prepared by ourselves for the analysis. These sheets are representing the construction achievements at the completion stage of a pier. For the section at hand, downward deflections were predicted at both sides of the pier during the erection and shim plates were used consecutively twice. However, the deflections could not be recovered. Consequently, it was judged that excessive shimming was not advisable and compensatin was provided by using the spare tendons during the erection of segment No. 12. This section shows that the erection trend differed from the fabrication trend, even if the fabrication error was rather small. However, the adjustment could be adjusted successfully also in such case through a series of compensation process.

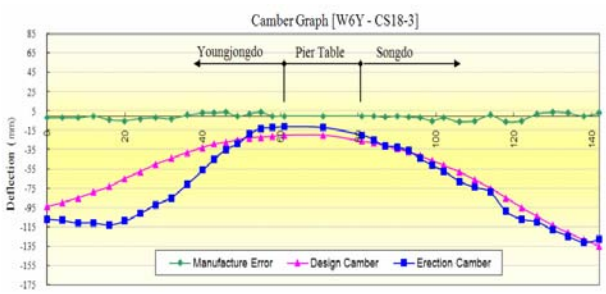


Figure 17: Fabrication and construction camber errors

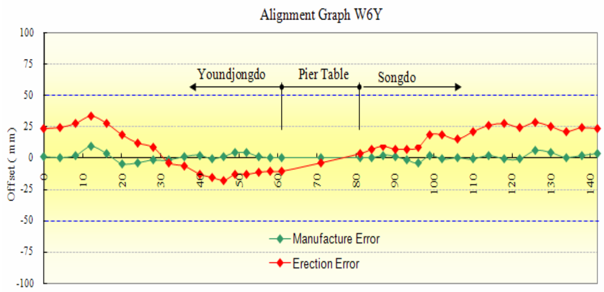


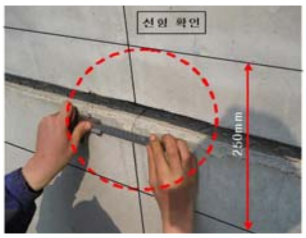
Figure 18: Alignment error

All along the erection geometry control process, the contractor and supervision team kept close and continuous collaboration to analyze the progress trend at each erection stage so as to perform the following erection task.

• *Superstructure Erection Process*

The vertical tendons (20 rows) of the large block is prestressed to unify with the large block and the pier. 37 ea of 15.2mm length steel strands is inserted per tendon. For the cantilever tendon, 19 ea of 15.2mm of steel strands is inserted, so a total of 48 rows are stressted. At the beginning of the work, 174 days were required for completion of 1 pier including large and small blocks, however, at the later work stage, only 58 days were required. The work period to erect all small blocks of east/west sections was 42 days.


Match cast block erection



MCB survey


Pier table erection


VT tendon prestressing

Derrick crane erection | Base segment setting | Normal segment lifting | Top tendon prestressing

Figure 19: Offshore erection process

3.3. ERECTION OF KEY SEGMENT

■ **Key segment jack-up system**

The erection of the key segment corresponds to the closure of the central span between two contiguous piers after the completion of the single cantilever erection. The original design planned to construct the key segment by using a derrick crane as shown in figure 20. However, the separate key segment jack-up system shown in figure 21 was adopted in order to ease the operation of the derrick crane. This system was conceived through the idea of a member of the construction team. When this concept was proposed, the supervision team verified the feasibility of its application by structural analysis and supported actively its concretization on the field. This relatively simple concept adds a jack-up system, which can exploit the planned leveling beam and steel wires and, realize maximum effect compared to the additional cost.

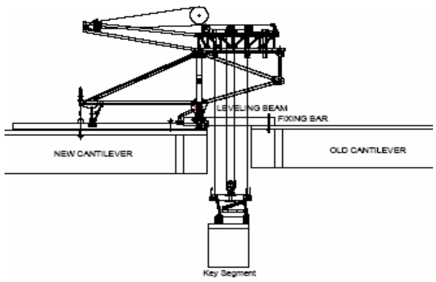


Figure 20: Lifting by derrick crane (original design)

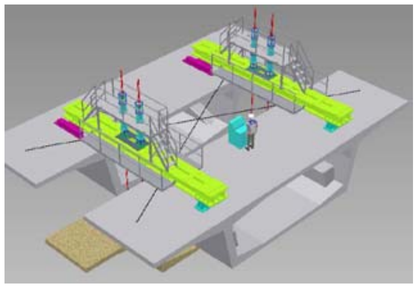


Figure 21 : Jack-up system (modified design)

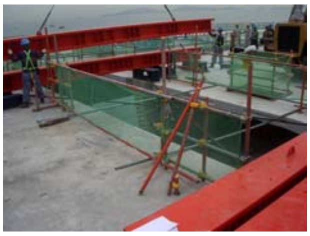
Using such concept, the operation of the derrick crane could be performed with focus on the erection of the small blocks and enabled significant shortening of the construction period. For the western approach bridge under construction at the time, erection was performed by applying a counterweight weighing the weight of the derrick crane in order to conform to the camber of the design. The concept was reflected in the final design of the eastern approach bridge while preserving the design features (fast track) of the site.

■ **Key segment construction sequence**

The construction process of the key segments using this system is as follows. First, the key segment is prepared on the barge and a counterweight corresponding to 50% of the lifting load is disposed at the top of the opposite cantilever. The levelling beam is installed on the cantilever under construction and the jack-up system is assembled on the beam. The lifting device is then fastened by inserting bundles of 4 strands in the two sets of 2-level modular jacks and the key segment is lifted. During lifting, the cantilever deflects downward due to the lifted weight and the levelling beam enters in contact with the previously constructed cantilever. The lifting of the segment is pursued until the top and the lifting wires are dismantled after the key segment is fixed to the levelling beam by means of steel rods. Then, the transverse displacement and vertical displacement are adjusted using the X-bar and levelling beam.

Once the geometry control is completed, the H-prop beam is installed on the bulk head inside the girder. During the closure stage at which the pre-compensation horizontal force is introduced, two bottom tendons per web are preliminary tensioned at $0.3f_{pu}$ (f_{pu} = 1,860MPa). If pre-compensation is not done, three bottom tendons per web are tensioned at $0.7f_{pu}$. At this time, check of tensioning force is executed

using the strain gauges disposed on the H-prop beam. Thereafter, the forms are installed for the placing of CIP concrete and placing is performed using a hopper fed by a floating BP barge. Once concrete secures the specified strength after curing, the remaining bottom tendons are tensioned and finishing is done by injection of grout inside the ducts. A total of 20 rows of lower tendons (19ea – 15.2mm) in each center span are stressed.

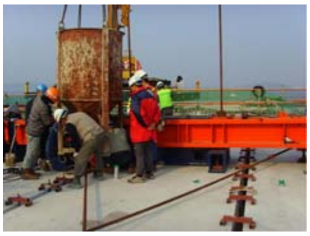

Leveling beam setting


Jack-up system


Key segment lifting


Surveying


H-prop beam setting


Cast-in-place concrete


Bottom tendon prestressing


Construction completion

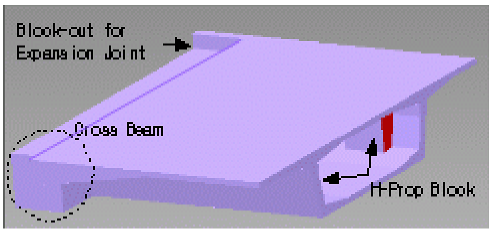
Figure 22: Construction process of key segment

3.4 END SEGMENT CONSTRUCTION

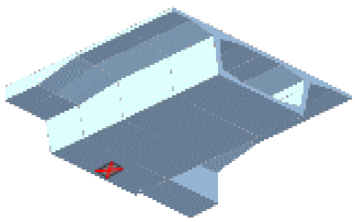
The erection of the final member that is the 11m-long end segment is performed after the construction of the whole set of key segments. This part was originally planned to be cast-in-place but the planning was modified onto the overall erection of precast members. This modification was implemented to overcome the disadvantageous offshore working conditions, secure the quality of the structure and shorten the construction period. The design of the eastern section was conducted through fast track while the western side was carried out through design revision.

■ **Fabrication of end segment**

The fabrication of the end segments was executed at proximity of the casting yard to ease the access of the 3000ton floating crane. The support was fabricated in block out state to dispose the segment at its exact position on the bridge bearings during the offshore fixation. This portion was planned to be filled with non-shrinkage mortar after fastening of the stud bolts. The fabrication was processed by 2 partitioned casting considering the workability and cracks were controlled through check by a separate hydration heat analysis.



End segment


Bottom of end segment

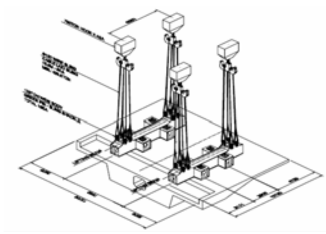
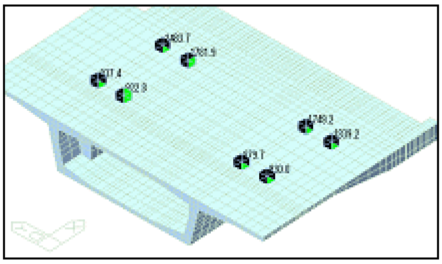

Lifting pattern

Figure 23: End segment Fabrication & Lifting pattern

On the other hand, figure 24 illustrates the solid analysis performed to dispose the lifting hole at the optimal position by checking the center of gravity (C.O.G) during lifting. Figure 25 shows the check of

the eventual occurrence of excessive local stresses when the segment is installed on the offshore pier bracket. This check led to the arrangement of additional reinforcement in the places subjected to stress concentration.


Check of lifting position

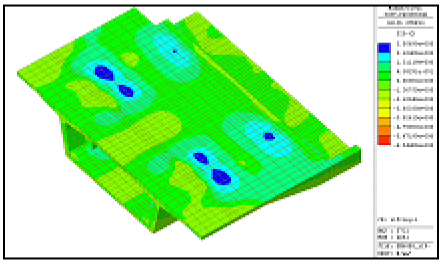
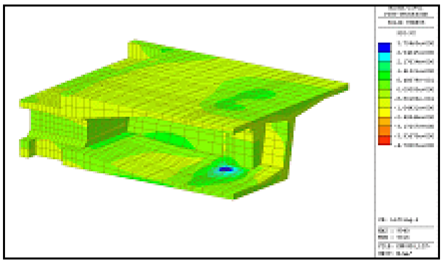

Check of stress around lifting hole

Figure 24: Solid analysis at lifting stage


Check of stress at supports(longitudinal)

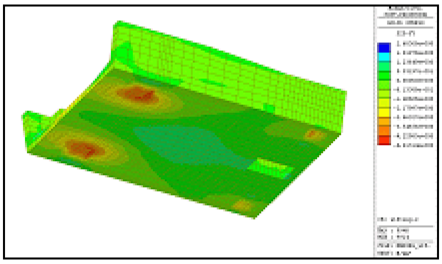
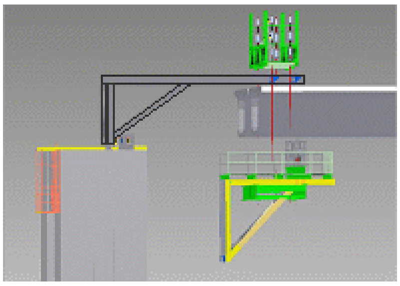
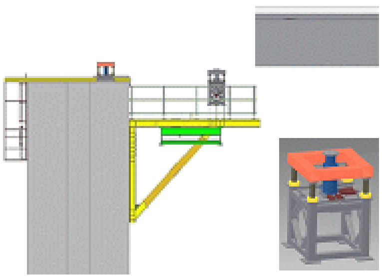

Check of stress at supports(transversal)

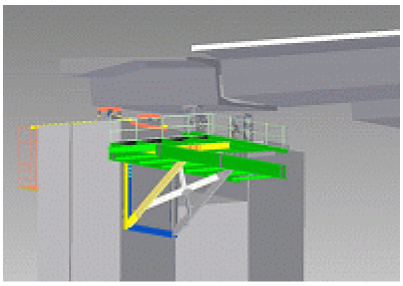
Figure 25: Solid analysis at fixation stage

■ **Pier bracket system**

The adoption of pier bracket system is necessary to install the 4 precast end segments offshore. The application of this system also necessitates separate lifting equipment composed by rails, traveller, lifting frame and jack-up device. Moreover, a temporary support, walkway and guide frame are additionally required to conduct safe setting during the erection of the end segments by the 3000ton floating crane.


Bracket Lifting system


Bracket system setting


End segment setting

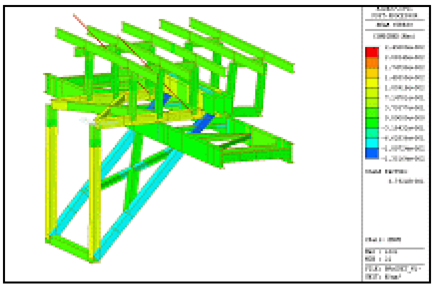

Calculation of stress

Figure 26: Pier bracket system

The brackets fabricated in the factory at a rate of 4 units per pier shaft were transported offshore by a barge and lifted using a lifting system. The brackets were then fixed by tensioning of the thread bars (ϕ40mm) inserted in 24 duct holes preliminary embedded in the pier. Two temporary supports were also installed at the top of each coping. Temporary damper-type supports were additionally installed to alleviate the impacts occurring during the setting of the end segments on the brackets. These temporary supports were planned to enable minute adjustments in all directions to achieve precise setting of the end segments.

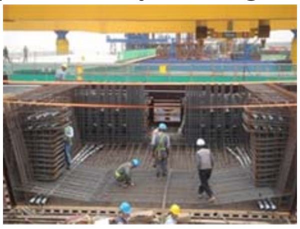
■ **End segment construction sequence**

Sliding pads were disposed at the bottom of the temporary supports and the setting of the temporary supports on the bracket and at the top of the coping was conducted in advance through precise measurement of their height prior to the erection of the end segments. Once the preparation completed, the end segment was lifted using the floating crane and setting was done at the exact position by means of the series of fine adjustment devices mentioned above.

Once the exact position was identified by measurement, the monolithic structure was achieved by placing non-shrinkage mortar in the block-outs connecting the bridge bearings and the end segment. After completion of placing, the H-prop beam was installed inside the girder to control the displacement of the cantilever according to temperature change and the specified compressive force was introduced by tensioning of the permanent steel rods and some of the bottom tendons. At this time, check of continuous introduction of the compressive force was done executed using the strain gauges disposed on the H-prop beam. And, the measuring instrument was disposed on the bracket member to check any abnormal displacement.

After completion of the installation and fixation of the H-prop beam inside the girder, the CIP form was installed and concrete was placed. The installation of the form and the placing method were identical to the placing method of CIP concrete for the key segment. Once the compressive strength exceeded 31.5MPa, all the remaining parts of the bottom tendons and permanent steel rods were tensioned and grouting of the ducts was performed. After completion of the erection of the end segments of the up and down lines, the 4m-long cross-beam connecting both end segments was constructed. The arrangement of reinforcement in this section is extremely complex and have very small working space. Therefore, cast-in-place construction was performed by dividing the first and second lanes.

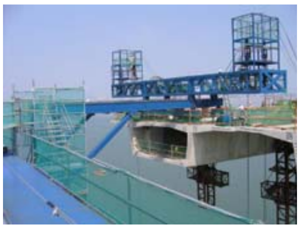

Manufacture of forms


Arrangement of rebar


Insulated curing

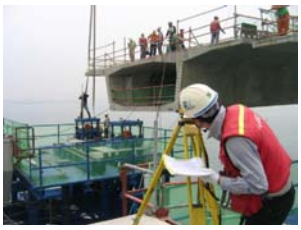

Completion of fabrication


Construction of bridge bearing


Bracket lifting system


Bracket lifting


Fixation of bracket


Installation of temporary support


Erection of end segment


Completion of setting


Placing of mortar


Measurement of faulting


Installation of leveling beam


Installation of H-prop beam


Placing of CIP joint


Tensioning of bottom tendon


Completion of closure

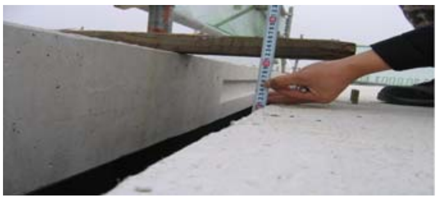

Construction of cross-beam


Dismantlement of bracket

Figure 27: View of end segment construction

■ Check of faulting effect according to temperature change

The fault occurred between the end segment installed above the bracket and the existing cantilever during the waiting time for close. The largest fault occurs under the maximum temperature a mid-day as shown in Figure 28. Figure 29 presents the results of the structural analysis considering this condition, and it is revealed that a downward displacement of about 116mm occurred at the end of the girder and that an elongation of approximately 40mm occurred in the transverse direction. Similar displacements were actually observed on the site. Therefore, the faulting observed in this section can be clearly attributed to the effect of temperature. Meanwhile, it was expected that cracking would be likely to develop on the CIP section of the end segment and the cantilever end during the setting period after concrete placement because of the said temperature effect. In order to prevent the cracking, a levelling beam was additionally installed at the top of all the subsequently erected end segments as shown in figure 30. The adjustment of the fault was performed in the early morning when temperature change was minimal using a hydraulic jack to fix the levelling beam and the girder. At that time, the superstructure system has temporary change of the boundary condition so it is important to let the temporary supports being operated by the sliding pad.



Ttemperature range for Uniform temperature (TU)
: 32°C–22°C = +10°C
Difference from top to bottom (TG): 39°C–26°C = +13°C
where, Measured temperature at part of girder directly exposed to sun rays = 39°C
Measured temperature at shaded part of girder = 26°C

Figure 28 Temperature Fault : Cantilever End

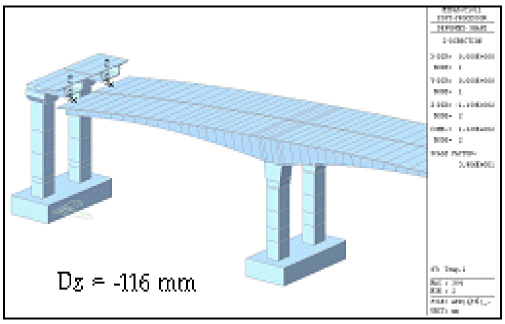


Figure 29 : Analysis Result & Temperature Displacement

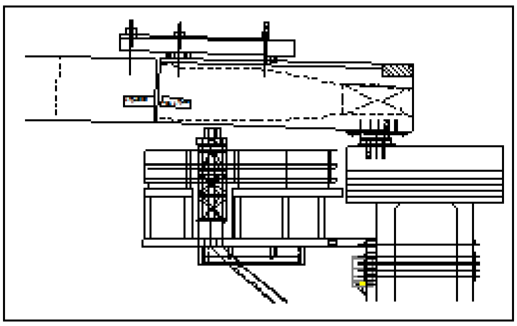


Figure 30 : End segment leveling Beam

3.5 Construction of external tendon

The external tendons were constructed after the installation of HDPE pipes inside the girder in order to achieve the continuity of the whole girders. For the external tendon, 37 ea of 15.2mm length steel strands were inserted into all span sections, and each 6 rows were tensioned once. And also, Anti-Vibration device was installed to prevent any failure of grouting and fatigue of the external tendons which may occur due to resonance during the vibration of the bridge caused by travelling vehicles. These devices were disposed at spacing of minimum 5.7m and maximum 12m to prevent the occurrence of modes exhibiting difference of their frequencies below 5% after comparison of the natural frequencies of the bridge and external tendons.

Connection of HDPE pipe   Installation of HDPE pipe   Insertion of external strand   Tensioning of tendons

Finishing of anchors   Grouting   Anti-vibration device   Completion of construction

Figure 31: Achievement of overall continuity using external tendons

3.6 Bridge Deck Pavement

Latex Modified Concrete (LMC) was paved after removal of foreign substances and laitance on the bridge deck plate by the surface milling. This construction method is required high initial cost, however, no additional water-proofing work is necessary. And also, the durability period is longer than other paving method (Ascon) so the maintenance cost might be reduced. The thickness of the pavement was 5cm, however, it was determined before paving work considering the analysis for the result of the paving work, the serviceability during the service period, the time-dependent displacement, etc.

(a) Bridge deck surface freatment(milling/shot blasting)   (b) LMC pavement

Figure 32 : View of Bridge Deck Pavement

4. CONCLUSIONS

In the above, several major construction items are presented, which were critically managed during the various technical reviews in the supervision works for the construction of the approach bridge in the Incheon Bridge adopted the precast free cantilever method. The apprehension and burden felt at the beginning of the construction were eradicated through a series of efforts to communicate and compare the technical review documents of both contractor and supervisor. We believe that these construction engineering activities led to mutually complementary roles in terms of construction management and allowed high quality and smooth progress of the construction and resulted in the success of the construction.
All the data that have been checked up to date could not be addressed due to the limited pages allotted to this paper. However, it is clear that the technical engineering activities are highly required for the construction of this kind of bridges. It is hoped that the items presented here could be utilized as a reference for the construction management tasks of future similar constructions. We express our deep gratitude to all the people who participated in this construction work day and night and without any safety accident to the construction work, even though the construction work is required high level of difficulty and executed on the marine site.

REFERENCES

[1] Kim, H.T. & Kang, B.S. 2007. Design and construction of the precast FCM approach bridge of Incheon Bridge. Technical Report No. 14 of Yooshin Corporation.

View of the approach bridge(PFCM) in Inchoen Bridge